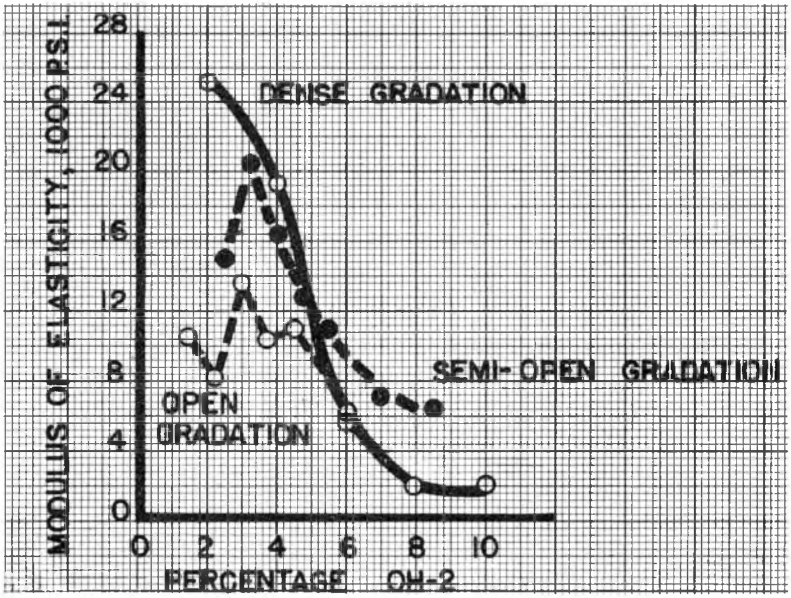

Fig. 7. Variation of modulus of elasticity with aggregate gradation and percentage admixture.

It is recognized that shearing resistance and stiffness are not the only criteria for a satisfactory bituminous-aggregate mixture. Adequate tensile strength, toughness, and weather resistance are also prime requisites in some instances. Although investigation of all of these factors has not been completed, the results to date suggest the possibility that maximum stability and minimum harmful base deflection would result from a lean, densely-graded, well-compacted base course and a richer, tougher riding surface of the same gradation.

THE USE OF AERIAL PHOTOGRAPHS IN IDENTIFYING GRANULAR DEPOSITS AND OTHER SOILS

J. E. Hittle, Research Engineer,
Joint Highway Research Project,
Purdue University

During the last two decades engineers have come to recognize the aerial photograph as a useful engineering tool. This can be more thoroughly appreciated if one considers that the aerial photograph is a permanent and detailed record of the physical and cultural land forms. Also, by use of stereoscopic pairs of photographs it is possible to gain an impression of the topography of the land forms depicted on the photographs. Such a record of the physical and cultural land forms is useful to the civil engineer in dealing with his problems of surveying, hydrology, geology, and municipal, highway, and airport engineering. Aerial photographs are particularly important in highway engineering, since the problems of the highway engineer are so broad and varied as to include most branches of civil engineering. For instance, in the design of drainage structures, aerial photographs provide an accurate and economical means of determining the size and shape of the watershed, the slope of the land and the character of vegetation, thereby enhancing the design of safer and more adequate drainage structures for our highways.

Also, aerial photographs have proved to be quite a useful expedient in dealing with highway location problems. In this respect aerial photographs probably have their widest application to highway engineering and, if properly utilized, a substantial saving in the cost and maintenance of the highway can be assigned to their use.

The preliminary reconnaissance survey of a proposed highway can be made almost entirely from an aerial survey of the locality of the proposed highway location. Naturally, the cultural and drainage features will be the important items to consider in the location of a highway over level terrain, while topography will be the important consideration of a highway location over rugged terrain.

Importance of Pedology

In recent years the highway engineer's attention has been called to the important role that soils play in the design, construction, and performance of the highway subgrade, since the source of many of the pavement failures can be traced to the type of soil used. More recently, highway engineers, through research, have come to recognize pedology as a convenient means of expressing the engineering characteristics of soils. Such a procedure lends itself well to the engineering practice of the highway engineer, since pedology not only takes cognizance of the stratification or horizon development of soils but also the areal distribution and differences in soils. This suggests the use of aerial photographs as a means of interpreting the general character of soils, and rightly so, since some of the factors influencing the development of pedologic types of soil, such as topography and drainage, are clearly shown on aerial photographs. Herein the aerial photograph offers the highway engineer a potential means of foretelling the soil problems that will be encountered in the course of a given highway location. In this way reconnaissance and relocation surveys can be made not only with respect to the cultural, drainage, and topographic features, but also with respect to the soil types to be traversed by the highway location and to sources of borrow and granular materials.

However, in order to interpret the general nature of soils from an aerial photograph, it is necessary to have a common understanding of pedologic factors which are responsible for the differences in soils and soil development.

Pedology is the name applied to the study of soils and the soil profile as influenced by the factors of soil formation. In one aspect, pedology is a branch of geology, since it is largely concerned with the physical and chemical weathering of the earth's surface. However, the field of pedology is quite broad; and it is not feasible to take up all of its aspects at this time, but rather only those which dominate the process of soil formation in Indiana soils, which are (1) topography, (2) drainage, and (3) parent material. Climate is another very important factor in the formation of soils; however, this factor does not create the differences in Indiana soils, since the climatic conditions in this state are essentially the same throughout.

If the parent material or, more specifically, that material from which the soil originated, is subjected to the temperate climatic conditions of moderately high rainfall and humidity for long periods of time, it will undergo alteration by both physical and chemical weathering. However, the agencies of chemical weathering predominate in the formation of soils in this region. In this process of chemical weathering the more soluble minerals of the parent material are dissolved, and under the action of percolating waters these dissolved minerals are translocated downward, whereupon the minerals are precipitated from the solution to form secondary products of weathering. As this process proceeds, there is also a tendency for the finer clay particles to be carried downward. Under the continuous action of percolating water, these secondary products of weathering and clay fines become differentiated into definite layers or horizons, the top, or "A," horizon being impoverished or eluviated and the second, or "B," horizon being enriched or *illuviated*. The unweathered parent material is commonly called the "C" horizon, and the complete succession of horizons down to and including the unweathered parent material is collectively referred to as the soil profile. (See Fig. 1.)

Soil Profile

The soil profile and all of its ramifications are of extreme importance to the highway engineer, since the grade line in many locations will approximate the ground line, in which case the soil for the subgrade would come from the top or

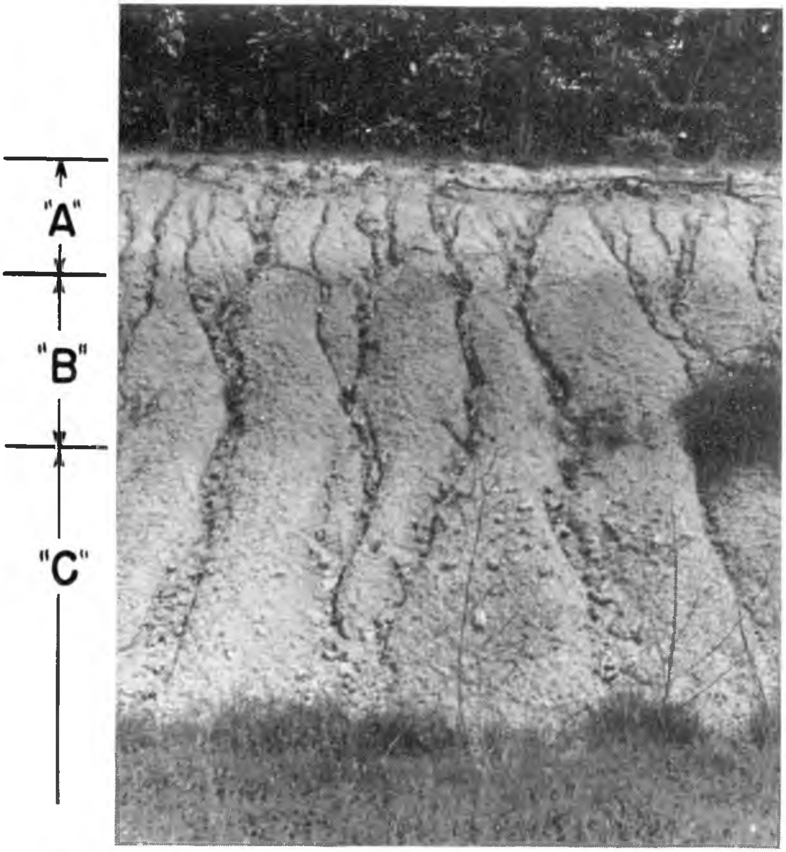

Fig. 1. This exposed highway cut shows a typical soil profile. The horizons are indicated.

"A" horizon. However, there are numerous situations where the grade line will intersect two or all of the horizons in a given soil profile, and evaluation of the soil from the various horizons of the profile by accepted engineering tests shows that the engineering properties of the soil vary throughout the profile, depending, of course, on the horizon being considered. Herein lies one of the important so-called "soil problems" of the highway engineer. While the foregoing description of the formation of the soil profile is of the simplest form, nevertheless it represents that which might well be termed as the "normal profile development" for this region of the United States.

Two of the factors which make for differences of soil profiles in Indiana are topography and drainage. These factors give rise to the soil catena or soil family, indicating a group of soils that has been derived from the same kind of parent material but differentiated by topographical and drainage conditions into distinct soil types, which are usually found in association with each other. These topographical and drainage conditions are reflected in the aerial photograph by contrasts in tone or color. Sharp contrasts in tone are usually indicative of profile development under the influence of a high water table. This is well illustrated in an aerial photograph in which the Miami-Crosby-Brookston-Clyde catena is represented. (See Fig. 2.) The soils of this catena are prevalent throughout northern and central Indiana, where the parent material is the calcareous till of the Wisconsin drift area. The light portions of the photograph represent the Crosby soils, which occupy the slightly undulating positions. The slightly darker tones of the photograph represent the Brookston soils, and the still darker tones in the vicinity of the drainage ditches represent the Clyde soils. Both the Brookston and Clyde soils occur on very flat and depressed topography and are formed under the influence of a high water table. Drainage problems will be encountered on highway locations traversing any of these soil types. Also, because of their plastic nature, the Brookston and Clyde soils make poor subgrade material from

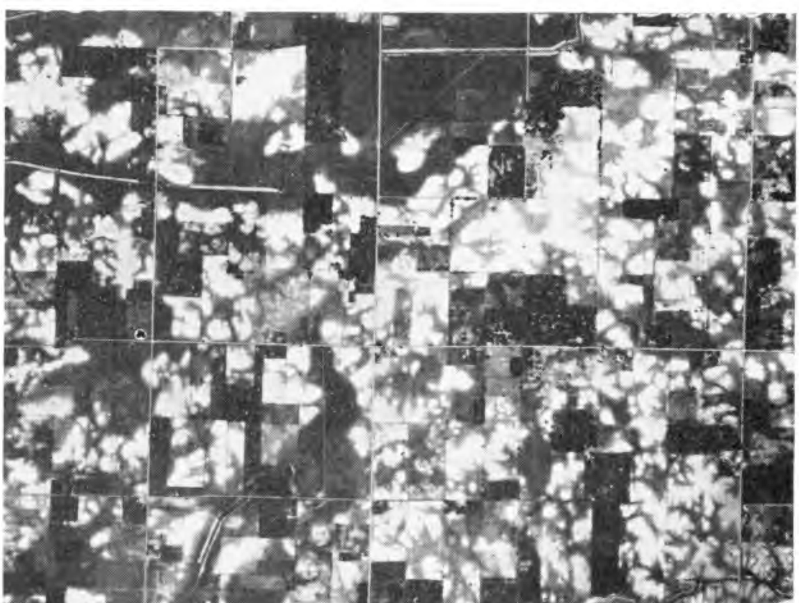

Fig. 2. An aerial photograph in which the Miami-Crosby-Brookston-Clyde catena is represented. Each of these soils can be identified on the aerial photograph on the basis of tone and color.

the standpoint of stability, and it is often advisable to elevate the grade line by means of a granular insulation course.

In regions having pronounced topography, the development of the soil profile is modified by erosion and run-off. The resultant effect is that the soil profiles occupying the hillside positions are weakly developed as compared to the soil profiles occurring on the hilltop positions. Under these conditions, the members of a given soil catena can be identified on the basis of topographic position alone, which in turn can be interpreted by viewing overlapping aerial photographs through a stereoscope. A good example of this type of catena development is the Fairmount-Switzerland-Allensville catena. This catena occurs in the southeastern part of the state where the parent materials are the Ordovician limestones and shales. The Switzerland soils have a well-developed profile and occupy the hilltop positions. The Fairmount soils occupy the hillside positions and have a very thin profile, since erosion takes place at about the same rate as the profile development. Neither of these soils presents any significant soil problems; however, slides may be encountered in the Fairmount soils, since bedrock is usually present at a depth of 20 inches.

As stated before, parent material is that unweathered material from which the soil profile is derived. Parent materials occur in several different forms and a majority of the different forms are represented in Indiana. On the basis of parent materials the state can be divided into three general areas: (1) the Wisconsin drift, (2) the Illinoian drift, and (3) the residual, in which the soils are developed from limestone, sandstone, or shale. It is interesting to note, however, that the chief differences in the soils from the Illinoian and Wisconsin drift areas are due to the factor of time. Since the Illinoian glacial period preceded the Wisconsin glacial period by several thousand years, the profile development is much more advanced in the Illinoian drift area. Also, within each of these areas are soils of alluvial and lacustrine origin. These are only a general classification of areas of parent materials and there may be wide variations within the area. This is especially true in the Wisconsin drift area where the parent material may be windblown sand or glacially deposited gravel, sand, or till. However, the soils in the three parent material regions are markedly different. This is at once apparent upon examining the soil profiles from the three areas.

Locating Granular Materials

Aerial photographs also provide the highway engineer with an effective means of locating granular materials. The location of sources of such material is becoming increasingly important to highway engineers since some of the known sources are becoming depleted. Also, highway engineers are recognizing the need for granular base courses as a means of improving the performance of pavement surfaces.

The majority of the granular deposits in Indiana are associated with rivers and streams. The reason for this is that our present drainage systems, as we know them today, were established during glacial times and were instrumental in the deposition of the granular deposits. It should be stressed here that granular deposits are associated with the smaller streams as well as the larger ones, since many of the streams, small though they may be today, were raging torrents during glacial times. This is especially true of streams having valleys disproportionate in size to their flow of water. An exaggerated form of this condition is what geologists term outwash plains.

The criterion for identifying granular deposits on aerial photographs is the absence of drainage features where they should normally be present. Such a condition is indicative of internal drainage, which in turn suggests the presence of granular material. This type of granular deposit is associated with rivers or streams, and occurs in the form of outwash plains or terraces.

An example of a granular terrace deposit is shown in an aerial photograph which includes the Wabash River. (See Fig. 3.) The gravel plant in the lower right portion of the

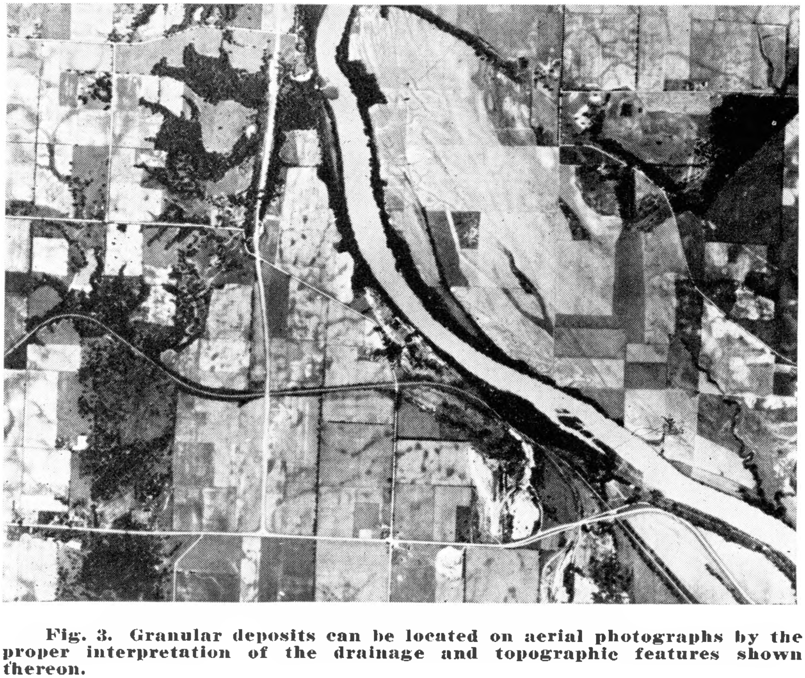

Fig. 3. Granular deposits can be located on aerial photographs by the proper interpretation of the drainage and topographic features shown thereon.

photograph is supporting evidence of the presence of granular material. However, note the dissected land forms on the left side of the photograph, whereas the lower center portion has an appearance of being flat and level but with no evidence of external run-off. The logical conclusion is that this area is being drained internally through a granular medium consisting of sand and gravel.

Granular deposits also occur in the form of mounds called kames or eskers. This type of deposit was also established during glacial times and can be recognized by its contrast to the surrounding topography. Typical examples of this type of deposit are found in northeastern Indiana where the last stages of the Wisconsin glacier deposited numerous kames and eskers; however, kames and eskers do occur singularly in isolated areas throughout central and northern Indiana and can be easily located by using stereoscopic pairs of aerial photographs.

While the examples of the various types of granular deposits cited herein are more easily recognized when the deposit is a large one, it should be remembered that there are hundreds of other lesser deposits which, when located and developed, can provide sources of granular material for base courses, fill construction, and county roads, and sand and gravel for aggregate.

THE DEVELOPMENT OF ENGINEERING SOIL MAPS

D. J. Belcher, Research Engineer,
Joint Highway Research Project,
Purdue University

The development of engineering soil maps is based upon the engineering problems created principally by the position and texture of soils and their influence on highway and runway performance. The object is to indicate those areas in which similar engineering soil problems can be expected to occur. The details can be carried to extremes, or only very general areas may be shown, according entirely to the use to which the map will be put and the extent of the area or accuracy of detail available. In the example herein developed, the final map contains areas of gravel soils, suitable for borrow; alluvial soils; depression soils, in which fills are desirable; soils occurring on 16 to 4 percent slopes, in which rather deep cuts are made; and soil areas occurring on 4 to 0 percent slopes, in which shallow cuts are common.